SYSTEM AND METHOD FOR REMOTELY DETECTING ELECTRIC ARC EVENTS IN A POWER SYSTEM

FIELD OF THE INVENTION

5   The present invention relates generally to power system maintenance and, more particularly, to a system and method for remotely detecting electric arc events in a power system.

BACKGROUND OF THE INVENTION

10   In many industries today, such as the avionics and automotive industries, complex and costly electrical components, systems and subsystems, as well as the electrical power systems powering these components, are interconnected by many bundles of conductors, typically wires, with each bundle including a plurality of wires. Although each wire is typically surrounded by insulation, or sheathing, such

15   wires can become faulty. In this regard, as the wires age, the insulation can breakdown and chaff. In such instances, the wires can contact other wires or other conductive structures, such as framework. Also, strands in aging wires can begin to separate and tear due to vibration, shock and stress on the wires. Stress due to pinching, rubbing, moisture, corrosion, excessive heat and/or lightening strikes also

20   pose risks that can lead to wire damage. Further, tight fitting connection points within connectors can loosen over time when subjected to the same environmental conditions as the conductors, and when subjected to numerous connects and disconnects due to replacement and maintenance of the electrical components, systems, subsystems, and the electrical power systems.

25   As will be appreciated by those skilled in the art, when the insulation surrounding the wires breaks down or chaffs, or the wire otherwise becomes faulty, undesirable electric arcs or other wire breakdown can occur at one or more locations along the wires, which can lead to breaks or shorts in the system. It will also be appreciated that in many instances, the location of such arc events or other wire

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breakdowns can be difficult to find. In this regard, the location of an arc event or other wire breakdown may be inside of a bulkhead or inside of a wire bundle. Also, an arc event may only brown an area of occurrence without actually burning through or burning the insulation away form the affected wire.

5   In many instances, detecting and locating the arc event or other wire breakdown can be difficult, if not impossible. In this regard, detecting a fault in the system as being caused by a faulty wire may be difficult in systems that also include complex electrical components, systems, subsystems and power systems. As such, misdiagnosing a fault in the system as being caused by costly electrical components,

10   for example, can result in unnecessary replacement of such components while still failing to correct the fault.

      In addition to the difficulty in detecting an arc event or other wire breakdown, locating such an arc event or other breakdown is also difficult. In many instances, the location of the arc event or other breakdown may be in a location that is impossible to

15   visually locate without extracting a wire bundle from the system. However, inspection of many feet of wire within a system can be very time consuming, and in some cases, may place maintenance personnel at risk for injury. Also, most conventional wire testing equipment is cumbersome and requires unique training of maintenance personnel as to how to use the equipment. Use of such equipment also

20   requires that one or more wire bundles be disconnected in order to test the wires. Unnecessary removal of equipment can also be very costly and time consuming, however, and can add to the required time to perform maintenance on the system. Further, many times such connection points are not located in easily accessed locations.

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SUMMARY OF THE INVENTION

      In light of the foregoing background, the present invention provides a system and method for remotely detecting an electric arc event. The system and method of embodiments of the present invention include at least one arc fault detector capable of

30   monitoring current to at least one load for conditions conducive to an electric arc event, which can damage the loads. The arc fault detector of embodiments of the present invention is capable of continuously monitoring current to the loads for an arc fault event such that, upon detection of such an event, current to the respective loads

can be shut off, thereby reducing the likelihood of the arc fault event becoming catastrophic.

According to one aspect of the present invention, a system is provided for remotely detecting and locating damaged conductors. The system includes at least one slave controller disposed proximate at least one load and electrically connected to the loads via at least one conductor. The slave controller includes at least one solid-state switch capable of controllably altering the input current to the loads, and at least one measuring element for measuring at least one parameter, such as at least one current parameter, associated with the loads and the solid-state switches. In this regard, the solid-state switches controllably alter the input current to the loads according to the parameters. The system also includes at least one arc fault detector electrically connected to the conductors between the slave controller and the loads. Advantageously, the fault detector is capable of detecting an electric arc event.

Each arc fault detector is capable of notifying a respective slave controller when the respective arc fault detector detects an electric arc event. As such, the solid-state switch of the respective slave controller can alter the input current to the at least one load. More particularly, the solid-state switches can operate in an on mode where the solid-state switches permit a respective load to receive the input current, and/or an off mode where the solid-state switches prevent the respective load from receiving the input current. In this regard, the solid-state switches can operate in the on mode such that when the at least one arc fault detector detects an electric arc event the solid-state switches are capable of being placed in the off mode.

The arc fault detector can detect an electric arc event in a number of different manners. For example, each arc fault detector can be capable of detecting an electric arc event by detecting white noise and/or chaotic behavior in current through the conductors to the loads. More particularly, each arc fault detector can be capable of detecting white noise by detecting a spectrally dense current through the conductors to the loads.

A method of remotely detecting an electric arc event is also provided.

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BRIEF DESCRIPTION OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

5   FIG. 1 is a block diagram of a system of remotely controlling at least one load according to one embodiment of the present invention;

FIG. 2 is a block diagram of a damaged wire detector according to one embodiment of the present invention;

FIG. 3 is a block diagram of a programmable controller including a single

10   solid-state switch and multiple measuring devices according to one embodiment;

FIG. 4 is a block diagram of a solid-state switch according to one embodiment of the present invention;

FIG. 5 is a graph illustrating a characteristic trip curve for a respective load and several current parameter measurements for the respective load;

15   FIG. 6 is a flow diagrams of a method of remotely controlling an input current from a master controller through at least one switch to at least one load according to one embodiment; and

FIG. 7 is a block diagram of another embodiment of the present invention including a damaged wire detector in addition to the arc fault detector.

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DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different

25   forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

FIG. 1 is an illustration of a system that would benefit from the damaged wire

30   detector of one embodiment of the present invention. This illustration is provided so that a more complete understanding of the present invention may be appreciated. It must be understood that the present invention is not limited to this configuration and may be embodied in many different power systems.

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With regard to FIG. 1, a general embodiment of a power system in which the present invention may be used is shown. The system, typically used to power devices onboard airplanes and automobiles, includes a programmable controller (i.e., slave controller) **10** disposed proximate and electrically connected to at least one load **14**,

5   such as one or more electrical components, systems and/or subsystems. For example, the programmable controller can be used to drive electric motors and servos, therefore replacing high maintenance hydraulic devices. The programmable controller can provide either alternating current (AC) current and voltage or direct current (DC) current and voltage to the loads, depending upon operation of the loads. As shown

10   and described herein, however, the programmable controller is particularly adapted to provide DC current and voltage the loads. But it should be understood that the programmable controller can equally provide AC current and voltage to one or more loads, as desired.

The programmable controller **10** can be electrically connected to the loads **14**

15   via electrical conductors, such as copper wires or the like. By using one programmable controller to control multiple loads, and by disposing the controller proximate the loads as opposed to in one central, humanly accessible location, cabling in the system is reduced which, in turn, reduces wiring losses in the system, and reduces the weight of the system. The programmable controller can be electrically

20   connected to a remote master controller **12**, such as a high-level processor or computer, which controls the input current to the loads through the programmable controller. Although the programmable controller can be electrically connected to the master controller, the programmable controller can additionally, or alternatively, be configured to operate independent of the master controller or any other type of

25   controller.

Electrically connected between the programmable controller **10** and the loads **14**, the system includes an arc fault detector **16**. The arc fault detector is capable of monitoring the current flow through the programmable controller for anomalies associated with an arc event. The arc fault detector can monitor current flow at any

30   time, but in one embodiment, monitors the current flow through the programmable controller after power has been applied, or as power is applied, to the loads to attempt to detect conditions conducive to an arc event before widespread damage occurs in the system.

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The programmable controller 10 and the remote master controller 12 can each draw power from a variety of sources as such are known to those skilled in the art. For example, in devices such as airplanes and automobiles, the programmable controller and remote master controller, in addition to the loads 14, can draw power

5   from the device's existing power bus. Additionally, or alternatively, the programmable controller and/or master controller can be connected to a stand-alone power source that supplies power to the programmable controller and/or master controller. The master controller of the system can additionally be connected to various other electrical systems within various devices. For example, in the

10   automotive industry, the master controller can interface with the vehicle management system and carry out the vehicle management system instructions to the loads in an autonomous fashion. It should be understood that, although the system illustrated depicts one programmable controller electrically connected to one master controller, a single master controller can be, and preferably is, electrically connected to multiple

15   remote programmable controllers without departing from the spirit and scope of the present invention. In turn, an arc fault detector 16 can be, and preferably is, electrically connected between each programmable controller and the loads connected to the respective programmable controller.

As previously mentioned, the master controller 12 controls the input current to

20   the loads 14 through the programmable controller 10. As such, the programmable controller can be used as a power relay or a circuit breaker, depending upon the desired application and the types of loads connected. As discussed below with reference to the programmable controller controlling the loads, the master controller controls the programmable controller by continuously monitoring the programmable

25   controller, controlling the output current from the programmable controller to the loads such as in on and off modes, selecting the various system parameters such as current, voltage and temperature limits, and programming the various system parameters into the programmable controller. Alternatively, or additionally, the programmable controller can be preprogrammed before integration into a device and

30   run free from control from the master controller. Therefore, throughout the description of the present invention, reference will only be made to the programmable controller. But it should be understood that the control features of the programmable controller can be performed by the master controller and/or the programmable controller. For more information on such a programmable controller, see U.S.Patent

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Application No. 09/842,967, entitled: *Programmable Controller For Remotely Controlling Input Power Through a Switch to a Load and an Associated Method of Operation*, filed April 26, 2001, the contents of which are hereby incorporated by reference in its entirety.

5   Reference is now drawn to FIG. 2, which illustrates a schematic block diagram of an arc fault detector **16** according to one embodiment of the present invention. Generally, an arc, as are most natural events, is composed of 1/f (pink) noise at low frequencies and white noise at higher frequencies. The arc fault detector **16**, then, is capable of monitoring the output current from the programmable controller **10** for

10   white noise of sufficient amplitude, which may be indicative of an arc event. For example, the arc fault detector can monitor the output current for amplitudes that exceed background noise by a predefined threshold. White noise may be defined as high spectral density (characterized by a multitude of frequency content), with a signal strength approximately equal in the same bandwidth irrespective of the

15   respective frequency examined. In addition, arc events can be characterized by chaotic behavior in signal strength. Thus, the arc fault detector, is further capable of monitoring the output current from the programmable controller for chaotic behavior which, along with the white noise, may characterize an electric arc event.

      The arc fault detector **16** can include a processing element **18** capable of

20   controlling operation of an arc fault detection module **20**, which may comprise analog circuit elements such as operational amplifiers, filters and comparators, as described more fully below. In this regard, the arc fault detector can include an oscillator **21** capable of driving the processing element to operate the arc fault detection module. The processing element is capable of signal processing a narrow band of current in the

25   audio region attempting to locate characteristics of an arc event. For example, the processing element can process the audio region to monitor the spectral density of the current in combination with chaotic amplitude changes. If high spectral density/chaotic amplitude changes are detected, the processing element can inform the programmable controller **10** which, in turn, can prevent current from being passed to

30   the loads, as described more fully below. In this regard, current having a high spectral density can be defined as that current with at least a portion present in all frequencies. Also, current with chaotic amplitude can be defined as that current lacking a pattern repetition.

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In the embodiment shown in FIG. 2, the arc fault detection module **20** can include a front-end high pass filter/gain stage **22** that feeds the output current (IANA) from the programmable controller **10** to a switchable band-pass filter **24**. The high pass filter/gain stage can comprise any of a number of different high pass filters, such

5   as a 8 kHz, 3 pole high pass filter. The high pass filter/gain stage is capable of attenuating strong load related components, such 60 and 400 Hz fundamentals and their associated harmonics when the programmable controller provides AC current and voltage to the loads, and capable of attenuating DC and low frequency switching currents when the programmable controller provides DC current and voltage to the

10   loads. By attenuating strong load related components, the high pass filter/gain stage can prevent the output current from driving the signals to the voltage rails of the other components in the arc fault detection module, as described below. The high pass filter/gain stage also provides some gain to signals above a predefined frequency (e.g., 8 kHz) to thereby facilitate detecting small arc fault characteristics in the output

15   current.

The band-pass filter **24** can comprise a state-variable analog filter, such as a 4 pole band-pass filter, having any of a number of bandwidths with any of a number of different selectable center frequency ranges. In one embodiment, for example, the band-pass filter has a bandwidth of approximately 500 Hz, and has a center frequency

20   selectable between 8 and 21 kHz. The processing element **18** can select the center frequency of the band-pass filter, such as by passing a digital center frequency selection through a digital-to-analog (D/A) converter **26**. The center frequency is advantageously selectable such that the processing element can monitor for characteristics that are indicative of electric arcs in all bandwidths, such as across the

25   entire upper audio region. In this regard, the band-pass filter slices out a spectrum of the output current from the programmable controller **10** within which to monitor for characteristics of an electric arc. And because an electric arc is spectrally dense, its presence will typically be identifiable in the audio range without interference from high frequency noise.

30   The output from the band-pass filter **24** can be fed into another gain stage **28**, which can pass the output to a current-differencing amplifier (CDA) **30**, a threshold detector **32** (described below) and a zero-crossing comparator **34** (described below). Advantageously, the CDA of one embodiment includes a diode front-end, which allows the CDA to operate as a very effective non-linear amplifier. In this regard, the

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CDA can generate sum and difference products. In other terms, the CDA can generate harmonics for sine and other than pure sine waves. However, if a signal is in a bandwidth between a lower frequency and a higher frequency, is complex and has spectral density, the output of the CDA can consist of all frequencies between 0 and

5   the difference between the higher and lower frequencies due to the difference. Similarly, the output of the CDA can also consist of all frequencies between two times the lower frequency and the sum of the higher and lower frequencies due to the sum. For example, for a signal in the bandwidth between 8 and 9 kHz that is complex and has spectral density, the output can consist of all frequencies between 0 and 1 kHz

10   due to the difference, and all frequencies between 16 and 17 kHz due to the sum.

The output of the CDA 30 can be AC coupled to remove any DC bias and then passed through a low pass filter 36, such as an analog 500 Hz low pass filter. The low pass filter can pass only the signal due to the difference, as processing the signal due to the difference is sufficient to monitor for spectral density. It will be appreciated,

15   however, that the amplitude of the signal due to the difference is not a measure of spectral density. To measure spectral density in the arc fault detection module 20 would require a very narrow band filter in place of the low pass filter to monitor for tight difference frequencies. Such a narrow band filter would add complexity to the arc fault detector 16, however, and still not guarantee spectral density as just two

20   slightly separated frequencies could produce the output.

The output from the low pass filter 36 is therefore passed through another zero-crossing comparator 37, which can have some hysteresis and reference offset (Vref). Thereafter, the processing element 18 can take timing measurements of the pulse edge-to-edge "scattering" within a certain time period (e.g., 20 msec) to

25   determine, and be certain of, the presence of frequencies in a specified band (e.g., 0 to 500 Hz). From the timing measurements, then, an arc event can be detected, such as by reviewing the measurements within the time period to determine whether the time between pulse edges and/or the width of the pulses vary in a random pattern. In addition to passing the output of the low pass filter to comparator 37, the output of the

30   low pass filter can also be passed as an analog signal (MIXANA) to the processing element. The processing element, in turn, can monitor the output for chaotic amplitude behavior. In this regard, the low frequency of the output signal facilitates the processing element finding and comparing local peaks to determine if a chaotic pattern exists between the peaks.

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As indicated above, gain stage 28 can pass the output from band-pass filter 24 to threshold detector 32 and comparator 34. The threshold detector, which can comprise a precision rectifier, is capable of measuring the signal strength in the selected frequency band of the band-pass filter. In this regard, if the signal strength exceeds a certain threshold level in each bandwidth, an electric arc may be present in the signal. From the threshold detector, the signal strength can be low pass filtered (not shown), and thereafter input to the processing element 18 as an analog signal (THRESDET).

Comparator 34 also receives the output from the band-pass filter 24, and thereafter passes the output to the processing element 18. Comparator 34, which can have some hysteresis and reference offset (Vref), allows the processing element to make timing measurements between pulse edges within the selected frequency band. In this regard, the processing element can control operation of the comparators 34, 37 via strobe signals (STROBE A and STROBE B) to each comparator. Spectral density will typically be evident in each band during an electric arc event. For example, spectral density can be determined from examining the zero crossings from the output of the gain stage 28. In this regard, if an electric arc having a very wide-band spectrum is band-pass filtered (utilizing band-pass filter 24), such as from 2 to 4 kHz, zero crossings from between 0.25 ms and 0.125 ms would be apparent. The output of the band-pass filter can be amplified (utilizing gain stage 28) to the point of clipping to make a 0 to 5 volt signal swing. The processing element can then count the time between the zero crossings for a period of approximately 50 ms, or about 100 samples. Thereafter, the processing element can use a technique, such as make timing measurements to check for a completely random pattern of the zero-crossings at all possible time intervals. As will be appreciated, a non-spectrally dense signal, like a square wave, would not pass such a test, even though the square wave has a lot of frequency content with the square wave's odd harmonics.

The processing element 18 is also capable of communicating with the programmable controller 10. In this regard, the programmable controller can clock data into and out of the processing element, such as the data utilized by the processing element to determine if an electric arc event is occurring, utilizing signal lines AFD CLOCK and AFD DATA as shown in FIG. 2. In addition, the processing element can transmit a notification, alert or the like to the programmable controller, such as when the processing element detects an electric arc event. As shown in FIG. 2, then, such a

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notification, alert or the like can be transmitted to the programmable controller utilizing the FAULT ALERT signal line.

Referring now to FIG. 3, the programmable controller **10** of one embodiment of the present invention includes a controller processing element **36**. The controller processing element can be any of a variety of processors, such as, for example, the PIC17C752 microcontroller manufactured by Microchip Technology Inc. The controller processing element monitors and controls the functions of at least one, and preferably multiple, solid-state switches **40**, discussed below. Not only does the controller processing element monitor and control the functions of the switches, the controller processing element also determines a condition of the switches and/or loads by performing calculations in the firmware using preconfigured characteristics and measured parameters of the switches and/or loads. The controller processing element allows the programmable controller to provide flexibility to the power system of the present invention not available with conventional circuit breakers or relays. By emulating the material limitations of conventional circuit breakers and relays with firmware, the controller processing element of the programmable controller overcomes the material limitations of conventional circuit breakers and relays, by having the capability to reprogram the controller processing element for different loads, as opposed to changing discrete components (i.e., conventional circuit breakers and relays). Also, the programmable controller allows for a wide variety of power control implementations to be programmed and made selectable by the system, such as various trip-curve implementations. In addition, the controller processing element can caution an operator if a dangerous condition is encountered, or the controller processing element can automatically control the respective switch accordingly.

The programmable controller **10** also includes at least one, and preferably more than one, solid-state switch **40**, each connected to a respective load **14**. While the illustration of FIG. 3 depicts only a single solid-state switch, it should be understood that the figure is for illustrative purposes only, and should not be taken to limit the scope of the present invention. In one embodiment, illustrated in FIG. 4, each solid-state switch includes a switching element **49**, a drive element **48** and a switch-protection element **46**. While the switching element can comprise any number of different solid-state switches, such as a MOSFET or an IGBT, the switching element acts to alter the input current to the respective load, typically operating in either an on mode wherein the switching element permits the respective load to

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receive the input current, or an off mode wherein the switching element prevents the respective load from receiving the input current. As previously stated, a solid-state switch eliminates the mechanical contacts of conventional circuit breakers and relays which, in turn, reduces the erosion and other problems associated with mechanical

5   contacts.

The solid-state switch **40** also includes a drive element **48** that provides the input current to the switching element **49**, and typically comprises circuitry consisting of conventional electrical components such as resistors, diodes and transistors. Additionally, the solid-state switch may include a switch-protection element **46** that

10   protects the switching element against instantaneous over-current conditions that could damage the switching element. The switch-protection element can comprise any of a number of different configurations, but, like the drive element, typically comprises conventional electrical components such as diodes, transistors, resistors and capacitors.

15   In operation, the switch-protection element **46** senses an actual current through the switching element **49**. If the actual current is above a predetermined value, such as a maximum current rating of the switching element, the switch-protection element alters the actual current through the switching element so that the actual current is no more than the predetermined value, typically placing the switching element in the off

20   mode. In some instances when the solid-state switch **40** is initialized at start-up, an inrush of actual current flows through the switching element. But while this current may be above the predetermined value, it typically settles down to a level at or below the predetermined value within a fairly short time. To account for this inrush of current and prevent the switch-protection element from prematurely altering the input

25   current, the switch-protection element of one embodiment is capable of waiting a predetermined amount of time before monitoring the level of current through the switching element. This predetermined amount of time allows the level of current to settle to a more constant, operation level before the switch-protection element monitors the switching element for instantaneous over-current situations.

30   Additionally, or alternatively, the switch-protection element can be configured to control the actual current in different manners at different times or in different modes of operation. For example, the switch-protection element can be configured to step down the predetermined value at which current is interrupted from an initial, elevated

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value to a stable, constant value at the conclusion of the predetermined amount of time.

Referring again to FIG. 3, the programmable controller 10 of the present invention includes at least one, and preferably more than one, measuring element that measures various conditions of the loads 14 and solid-state switches 40. For example, the programmable controller may include a current measuring element 38 and/or a voltage measuring element 42 that measure the input current through and voltage drop across a respective load. Additionally, the programmable controller may include a temperature measuring element 44 that measures the temperature at or around the solid-state switch. The current and voltage measuring elements are typically made from conventional electrical components such as resistors, capacitors and operational amplifiers. Also, the temperature measuring device can be made from any number of devices, such as the LM75 digital temperature sensor, manufactured by National Semiconductor. In operation, the measuring elements protect the loads 14 and/or solid-state switches 40 from undesirable conditions such as over-current, over and under voltage, and over and under temperature conditions by comparing such measured parameters against predetermined values for the respective load and/or switch. For example, the predetermined value for each load may be based upon material characteristics of the load, such as a maximum current or voltage rating, or a minimum operational voltage. Also, for example, the predetermined temperature value for each solid-state switch may comprise a maximum temperature rating for the respective solid-state switch, over which damage is caused to the solid-state switch. Additionally, the predetermined value based upon current or voltage rating characteristics can additionally take into account the predetermined temperature value because the current and voltage characteristics of various loads typically change over a range of temperatures.

Referring to FIG. 5, typically, the controller processing element 36 compares the measured parameters against the predetermined values by first constructing a model trip curve 50 comprising a plurality of measured parameter values at different points in time. The controller processing element compares the model trip curve against a characteristic trip curve 52 for the respective load and/or switch. The characteristic trip curve is typically predefined based upon a characteristic of the switch and/or load associated with the particular parameter, such as a current rating characteristic trip curve associated with the measured input current through the switch

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and/or to the load. FIG. 5 illustrates a characteristic trip curve along with a constructed model trip curve for a switch and/or a load with a ten amp current rating. Although not illustrated, the characteristic trip curve can additionally be predefined based upon a combination of the various parameters associated with the switch and/or

5 load, such as the temperature of the switch and/or load along with another parameter of the switch and/or load since many parameters of the switch and/or load may vary depending on the temperature of the switch and/or load. The characteristic trip curve is stored by the controller processing element or an associated memory device, thus making any trip curve implementation possible, such as I^2T and tiered. The

10 predetermined values of the characteristic trip curve are defined to prevent the solid-state switch and/or load from operating too long in a dangerous area **56**. By referencing the characteristic trip curve, the controller processing element can keep the measured parameter in a safe area **58**, such as below the current rating of the switch and/or the load, and turn off the switch before the switch and/or load can be

15 damaged by crossing a critical point **54** on the characteristic trip curve. If the condition measured by the respective measuring element falls outside the range of predetermined values or above the predetermined value or, more typically, if the model trip curve constructed by the controller processing element based upon the measured parameter or parameters is predicted to reach the critical point on the

20 characteristic trip curve, the controller processing element alters the input current through the solid-state switch accordingly. For example, if the controller processing element in conjunction with the measuring element determine that the input current to the load will remain at or above a certain level for more than the maximum time permitted by the characteristic trip curve within a predefined period of time, the

25 controller processing element can alter the input current to bring the measured value within the predetermined value range or below the predetermined value or, preferably, the controller processing element can place the solid-state switch in the on or off mode.

In another advantageous embodiment, when the input current to the switch

30 and/or the load reaches or exceeds a certain level, such as a maximum current rating or an input current rating, respectively, the controller processing element repeatedly increases a count. If the count exceeds a predetermined threshold representative of the predefined period of time, the controller processing element can alter the input current to reduce the input current to below the certain level, such as by placing the

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switch in the off mode. But if the input current to the load decreases to below the certain level before the count exceeds the threshold, the controller processing element will repeatedly decrease the count. In this regard, the controller processing element can account for previous current stress (e.g., excess current) to the switch and/or the load should the switch and/or the load experience a subsequent current stress before the count reaches zero since the count would begin upward again, although not from zero but from a value representative of the residual stress on the switch and/or the load.

Referring now to FIG. 6, a method of remotely controlling the input current from the controller processing element **36** through each switch **40** to each load **14**, according to one embodiment of the present invention, begins by configuring the firmware of the controller processing element based upon the desired characteristics of the switches and loads, such as current and voltage ratings of each load, a maximum current rating of each switch and/or a temperature rating of each switch, as shown in block **100**. For example, the firmware can be configured with the characteristic trip curves typically predefined based upon the characteristics of the switch and/or load. Additionally, the characteristic trip curves can be predefined based upon a combination of the various characteristics of the switch and/or load, such as the temperature of the switch and/or load along with another parameter of the switch and/or load since many parameters of the switch and/or load may vary depending on the temperature of the switch and/or load. Thus, different characteristic trip curves can be utilized depending upon the temperature of the switch. Additionally, or alternatively, the characteristics of each switch related to current through the switch, such as the maximum current rating, can be configured into the respective switch-protection element **42** to monitor the actual current through the respective switch. Advantageously, by configuring the controller processing element with the characteristics of the switches and loads, if a switch or load with different characteristics is connected to the power system, the controller processing element can be reconfigured such as by constructing and storing the characteristic trip curves associated with the different switch or load, as opposed to replacing the discrete components of conventional circuit breakers and relays.

After the controller processing element **36** has been configured, each switch **40** is operated in the on mode, as desired, to provide the input current to the respective load **14**, as shown in block **102**. As the switch is operating in the on mode, the

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switch-protection element senses the actual current through the switch, as illustrated in block **104**. If the actual current is above a predetermined value, such as the maximum current rating of the switch, the switch-protection element can wait a predetermined amount of time to allow any inrush of current to settle to a stable level,

5 as shown in blocks **106** and **108**. Additionally, or alternatively, the switch-protection element can be configured to control the actual current at different times or in different modes of operation. For example, the switch-protection element and/or controller processing element can be configured to step down the predetermined value from an initial, elevated value to a stable value at the conclusion of the predetermined

10 amount of time. If, after the predetermined amount of time the actual current is still above the predetermined value, the switch-protection element reduces the actual current, such as by placing the switch in the off mode, as shown in blocks **111** and **120**. In the event the actual current is below the predetermined value, either initially or after the predetermined period of time, the switch-protection element continuously

15 monitors the actual current to ensure the actual current remains below the predetermined value, as shown in blocks **110** and **111**.

As the switch-protection element **46** monitors the switch **40** for an over-current situation, the controller processing element **36** periodically samples the current and/or voltage through and/or across the load **14**, and/or samples the

20 temperature of or around the switch to use to obtain a condition of the load and/or switch, as illustrated in block **112**. The condition is then determined by comparing the current, voltage and/or temperature against the characteristics predefined by the controller processing element.

The controller processing element can determine if an over temperature or

25 under temperature condition exists in the switch, as shown in block **114**. And if so, the controller processing element can alter the input current accordingly. For example, the temperature measuring element can measure the air temperature at or around the switch and compare the measured temperature against the predetermined values for the desired temperature range, such as critical temperature limits. If the

30 measured temperature is below or above the desired temperature range, the controller processing element can place the respective switch in the off mode to prevent the switch from being damaged or from damaging the respective load, as shown in block **120**. Alternatively, the controller processing element can construct different characteristic trip curves based upon other parameters to emulate the temperature at or

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around the switch based upon characteristics of the switch that vary in proportion to the temperature of the switch.

The controller processing element can also determine if an over voltage or under voltage condition exists in the load 14 and alter the input current accordingly, as shown in block 116. For example, if the measured voltage drop across a respective load falls outside the preconfigured voltage range for the respective load, the controller processing element 36 can alter the input current to place the voltage drop within the desired levels or place the respective switch 40 in the off mode.

The controller processing element 36 can also determine if an over current condition exists in the load 14 and, if so, alter the input current to below the predetermined level, as shown in block 124. For example, the controller processing element can determine a model trip curve 50 using a plurality of measured parameter values at different points in time. The controller processing element compares the model trip curve against the characteristic trip curve 52 for the respective load and/or switch 40. The predetermined values in the characteristic trip curve are defined to prevent the switch from operating too long in the dangerous area 56. Additionally, the controller processing element can account for previous current stresses (e.g., previous switch operations in the dangerous area) by maintaining a count. As the switch operates in the dangerous area, the controller processing element repeatedly increases the count. And if the switch returns to operating outside of the dangerous area before the count reaches a predetermined threshold (representative of the maximum amount of time the switch is allowed to operate in the dangerous area), the controller processing element can repeatedly decrease the count as long as the switch remains outside the dangerous area, as previously described. By referencing the characteristic trip curve, the controller processing element can turn off the switch before the switch and/or load can be damaged, such as by placing the switch in the off mode, as shown in block 120.

Also, in accordance with embodiments of the present invention, as the switch 40 is operating in the on mode, the arc fault detector 16 continuously monitors the output current of the programmable controller 10 for characteristics identifying an arc event, such as in a manner described above and as shown in block 119. If the arc fault detector detects an arc event, then, the arc fault detector can notify the programmable controller, which can respond by placing the switch in the off mode. If the arc fault detector does not detect an arc event, however, the arc fault detector can continue to

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monitor the output current of the programmable controller for characteristics identifying an arc event.

In another embodiment of the present invention, shown in FIG. 7, the system can further include a damaged wire detector **70** electrically connected between the
5   programmable controller **10** and the loads **14**. In this embodiment, the damaged wire detector is capable of monitoring the impedance conditions associated with the conductors connecting the programmable controller to the loads, as well as the loads. Typically, the conductors can be tested before applying power to the loads to thereby prevent malfunction in the system upon applying power to the loads. The damaged
10   wire detector can detect a damaged wire and locate the damage in any of a number of different manners, such as according to a time domain reflectometry technique.

For instance, when the arc fault detector identifies characteristics of an arc event, the damaged wire detector can be utilized to attempt to locate damage caused by such an arc event. In this regard, if an electric arc is detected when flash point
15   occurs and the electric arc grows, the electric arc itself may act as a resistor. In such instances, then, the location of the flash point can be detected by the damaged wire detector **70** as the point where a test pulse reflects off of the point due to the resistance caused by the electric arc. If the reflection does not indicate a "resistor growth," then, the alert of the arc fault detector **16** can be considered a nuisance trip and shutdown
20   can be prevented. For more information on such a damaged wire detector, as well as the system including both the arc fault detector **16** and the damaged wire detector, see U.S. Patent Application No. _____, entitled: *System, Damaged Wire Detector and Method for Remotely Detecting and Locating Arc Fault Events in A Power System*, filed concurrently herewith; and U.S. Patent Application No.
25   _____, entitled: *System, Supplemental Protection Module and Method for Remotely Detecting and Locating Faults in A Power System*, filed concurrently herewith, the contents of both of which are hereby incorporated by reference in their entirety.

Many modifications and other embodiments of the invention will come to
30   mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are

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employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

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